Do Synergistic Relationships between Nitrogen and Water Influence the Ability of Corn to Use Nitrogen Derived from Fertilizer and Soil?

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Nitrogen Management

ABSTRACT

To improve site-specific N recommendations a more complete understanding of the mechanisms responsible for synergistic relationships between N and water is needed. The objective of this research was to determine the influence of soil water regime on the ability of corn (*Zea mays* L.) to use N derived from fertilizer and soil. A randomized split-block experiment was conducted in 2002, 2003, and 2004. Soil at the site was a Brandt silty clay loam (fine-silty, mixed, superactive frigid Calcic Hapludoll). Blocks were split into moderate (natural rainfall) and high (natural + supplemental irrigation) water regimes. Nitrogen rates were 0, 56, 112, and 168 kg urea-N ha^{-1} that was surface applied. Water, soil N, and N fertilizer use efficiencies were determined. Plant utilization of soil N was determined by mass balance in the unfertilized control plots and by using the δ^{15}N approach in fertilized plots. Findings showed that: (i) plants responded to N and water simultaneously; (ii) N fertilizer increased water use efficiency (170 kg vs. 223 kg grain cm^{-1} in 0 and 112 kg N ha^{-1} treatments, respectively); and (iii) water increased the ability of corn to use N derived from soil (67.7 and 61.6% efficient in high and moderate water regimes, respectively, P = 0.002) and fertilizer (48 and 44% efficient in high and moderate water regimes, respectively, P = 0.10). Higher N use efficiency in the high water regime was attributed to two interrelated factors. First, total growth and evapotranspiration (ET) were higher in the high than the moderate water regime. Second, N transport to the root increased with water transpired. For precision farming, results indicate that: (i) the amount of N fertilizer needed to produce a kg of grain is related to the yield loss due to water stress; and (ii) the rate constant used in yield goal equations can be replaced with a variable.

Regional N recommendation models, such as the line-response plateau N recommendation models, as shown in Fig. 1, are the result of broad compromises of some soil fertility specialists (Pan et al., 1997). Even though these models were not designed for site-specific applications, they are being used for this purpose (Chang et al., 2004; Koch et al., 2004). Many regional corn N models have the general form, N recommendation = k × yield goal–credits. The rate constant, k, typically ranges from 21.4 to 26.8 kg N (Mg grain)$^{-1}$. Validations of these models have shown weak to no relationship between measured and predicted economic optimum N rates (Bundy, 2000; Lory and Scharf, 2003; Derby et al., 2005). Based on these results, Iowa, Minnesota, and Wisconsin adopted alternative N recommendation models (Sawyer et al., 2006). Poor relationships between predicted and measured N responses has been attributed to: (i) scaling rules violations when models designed for regional applications are applied at field and subfield scales; (ii) equations that do not consider synergistic relationships between crop limiting factors, mineralizable N, ammonium N, and landscape position differences in plant available water (Clay et al., 2006b); and (iii) models that do not provide the flexibility needed to adequately describe cropping systems (Black, 1993). For precision farming, techniques for overcoming inherent limitations associated with regional N models are needed.

It may be possible to overcome limitations associated with regional models by increasing the complexity of the current equations or developing new models. The Mitscherlich et al. (1923) "Law of Physiological Relationships" may provide the theoretical basis for new site-specific recommendation models. This law as explained by Sumner and Farina (1986) says that, "Yield can be increased by each single growth factor even when it is not present in the minimum, so long as it is not present in the optimum." This theory has been interpreted to mean that yield responses are curvilinear and limiting factors can produce synergistic relationships (Black, 1993). Synergistic activities can result when one factor influences the ability of plants to use the second factor. Although not understood, synergistic relationships have been widely reported in the literature (Sumner and Farina, 1986). A goal of this research is to provide incites into the causes of synergistic relationships between water and N. The objective was to determine the influence of soil water regime on the ability of corn to use N derived from fertilizer and soil.

MATERIALS AND METHODS

This research was conducted at Aurora in eastern South Dakota in 2002, 2003, and 2004. The longitude and latitude

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Abbreviations: ET, evapotranspiration; HI, harvest index; NUE, nitrogen use efficiency; WUE, water use efficiency.

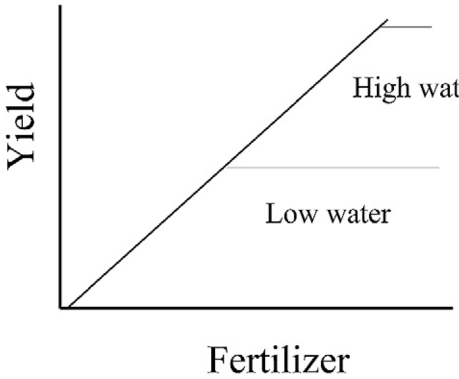

Fig. 1. An example of a line/plateau model that has been used for N fertilizer recommendations.

were 96°40′ west and 44°18′ north, respectively. No-tillage was used at the research site and the previous crops were soybean [*Glycine max*(L.) Merr.], wheat (*Triticum aestivum* L.) and soybean in 2001, 2002, and 2003, respectively. The soil parent materials were loess over glacial outwash. The soil series was a Brandt silty clay loam. The surface horizon contained approximately 110 g sand, 580 g silt, and 310 g clay kg^{-1}. Total N in the 0 to15 and 15 to 60 cm depths were approximately 5.1 and 10.2 Mg N ha^{-1}, respectively. Total C in the 0 to 15 and 15 to 60 cm depths were approximately 44.6 and 78.5 Mg C ha^{-1}, respectively. Additional information about the site is available in Clay et al. (1994) and Clay et al. (1995). The DKC 44–46 RR Bt corn hybrid (Monsanto Co, St Louis, MO) was planted on 3 May in 2002 and on 7 May in 2003. The DKC 47–10 RR Bt corn hybrid was planted on 5 May in 2004. Corn was planted at a population of 80,000 plants ha^{-1}. The DKC 44–46 and DKC 47–10 hybrids required 1311 and 1344 GDD (base 10°C) to physiological maturity.

The experiment used a randomized split complete block design. Blocks were split by soil water regime. The two soil water regimes were natural rainfall and rainfall plus supplemental irrigation. In 2002, 2003, and 2004, natural precipitation was 59, 44, 48 cm of water, respectively, of which 42.5, 32.9, 37.8 cm occurred during the growing season (Table 1). Corn growing in the supplemental irrigation treatment received an additional 10.8, 14.7, and 10 cm of irrigation water in 2002, 2003, and 2004, respectively. Within a water regime four N treatments (0, 56, 112, and 168 kg urea-N ha^{-1}) were surface applied after planting. The $\delta^{15}N$ of the urea fertilizer was −1.45‰. Each treatment was replicated four times and the plots were 15 by 14 m.

At physiological maturity, grain and stover samples from 9.3 m^2 area in each plot were hand-harvested. After drying and shelling, grain, stover, and cob yields were determined. Subsamples were dried, ground, and analyzed for total N, $\delta^{15}N$, and ^{13}C isotopic discrimination (Δ) on a 20–20 Europa Ratio mass spectrometer (PDZ Europa, Cheshire, UK) (Farquhar and Lloyd 1993; O' Leary 1993; Clay et al., 2001a). Plant $\delta^{13}C$ values were used to calculate yield losses due to water and N stress that were reported in a companion paper (Clay et al., 2006b).

Soil samples from three depths (0–15, 15–30, and 30–60 cm) were collected before planting and post harvest. Spring samples were collected from each block while fall samples were collected from each plot. Each sample was a composite of 10 individual cores. Soil samples were analyzed for gravimetric soil moisture and inorganic N. For inorganic N analysis, soil samples were air-dried (35°C), ground (2mm), extracted with 1.0 *M* KCl, and analyzed for ammonia and nitrate N using the phenate and Cd reduction methods, respectively (Maynard and Kalra, 1993). Preseason inorganic N (NO_3– and NH_4–N) were 101, 101, and 99 kg N ha^{-1} in 2002, 2003, and 2004, respectively. Dry bulk densities were used to convert gravimetric values to volumetric values. Bulk densities were measured in the spring of 2003 (20 May 2003) and 2004 (20 July 2004). Bulk densities were measured by collecting two cores from each block with either a 3.8 or 5.1 cm diameter probe. Each core was separated into 0- to 15-, 15- to 30-, 30- to 45-, and 45- to 60-cm depth segments. Each segment was oven dried (105°C) and weighed.

Crop ET was calculated as the remainder of the water balance:

$$ET = I + P - R - D - \Delta\Theta \quad [1]$$

where I is irrigation (cm ha^{-1}), P is precipitation (cm ha^{-1}), D is the drainage of water vertically downward out of the root zone (cm ha^{-1}), R is runoff (cm ha^{-1}), and $\Delta\Theta$ is the change of water storage (cm ha^{-1}) in the surface 60 cm. Rain-gauges were used to measure irrigation rates. Water budget calculations assumed precipitation was effective, runoff was zero, and that the application efficiency of supplemental irrigations was 100% (Oweis et al., 2000). These assumptions were based on the land being well drained, flat, and well managed. Capillary water rise was assumed to be insignificant because the water table was located 5 m below the soil surface and parent materials were loess (surface 60 cm) over glacial outwash (60 cm–20 m). Weekly soil moisture measurements from a neutron probe, were used to calculate daily drainage values (Miller and Aarstad, 1994). Based on these calculations, drainage values over the growing season

Table 1. Monthly average precipitation (prep.) and temperatures (temp.) during the study period.

	30-yr Average		2002		2003		2004	
Month	Prep.	Temp.	Prep.	Temp.	Prep.	Temp.	Prep.	Temp.
	cm	°C	cm	°C	cm	°C	cm	°C
January	0.86	−11.7	0.58	−7.1	0.58	−9.7	0.89	−11.5
February	1.02	−7.8	0.10	−3.1	0.58	−10.6	0.94	−8.7
March	3.28	−1.1	5.41	−7.9	0.25	−2.1	2.92	1.7
April	5.16	6.8	3.28	6.2	4.95	7.8	4.11	7.6
May	7.49	13.7	7.85	10.9	6.96	12.2	15.77	12.2
June	10.74	18.9	6.17	20.9	8.38	18.0	6.81	16.9
July	7.90	21.5	6.86	24.1	7.01	21.4	11.10	20.2
August	7.47	20.3	18.34	20.3	5.61	21.3	2.31	17.2
September	6.30	15.1	3.53	16.4	5.00	14.3	0.00	17.2
October	4.52	7.9	6.88	3.9	2.74	8.8	1.45	8.5
November	2.54	−1.1	0.00	−0.7	0.81	−2.8	1.17	1.8
December	0.66	−8.7	0.43	−4.8	0.74	−5.3	0.23	−5.4
Annual	57.94	6.2	59.43	79.1	43.61	73.3	47.70	77.7
April–August	38.76	74.5	42.50	76.2	32.91	72.8	37.79	66.5

(May–October) were near zero (<1.7 cm) for all plots and years.

Plant N uptake of the aboveground plant parts was determined by summing the N contents of grain and stover. Grain N use efficiency in fertilized plots (%NUE) was calculated with the equation:

$$\%NUE = [(N_{plant} - N_{control})/ N\ rate] \times 100 \quad [2]$$

where N_{plant} is the N contained in grain in fertilized treatments, $N_{control}$ is N contained in the grain of the unfertilized plot within the block, and N rate was the amount of applied N (Clay, 1997).

In the unfertilized control plots, the percentage of soil N used was calculated with the equation,

$$\%soil\ N\ use = (Biomass\ N_{control}) \times 100/(Inorganic\ N_{start} + N\ net\ balance) \quad [3]$$

where, N net balance for moderate and high water regimes within a block was calculated with the equation,

$$N\ net\ balance = Aboveground\ biomass\ N + inorganic\ N_{end} - inorganic\ N_{start} \quad [4]$$

The net N balance was slightly lower in the moderate than the high water regime. The higher N balance in the high water regime system was attributed to the irrigation water containing nitrate (15–40 NO_3–N µg g^{-1}). Equations [3] and [4] were based on the assumption that denitrification and deep nitrate loss were near zero.

The percent contribution of soil N to the plant in the fertilized plots was determined using the equations,

$$N_{soil} = 100 \times \{1 - [(\delta^{15}N_y - \delta^{15}N_x)/ (\delta^{15}N_y - \delta^{15}N_c)]\} \quad [5]$$

where $\delta^{15}N_x$, $\delta^{15}N_y$, $\delta^{15}N_c$ were the $\delta^{15}N$ values of the fertilized plants (N_x), unfertilized control plants (N_y), and fertilizer [$\delta^{15}N_c$ (urea) = −1.45 ‰], respectively (Clay, 1997). The $\delta^{15}N$ value was defined by the equation,

$$\delta^{15}N = (R_{sample} - R_{standard})/(R_{standard}) \times 1000‰ \quad [6]$$

where R_{sample} was the $^{15}N/(^{15}N+^{14}N)$ ratio of the sample and $R_{standard}$ was the natural abundance of ^{15}N (0.003663).

Grain and aboveground biomass water use efficiencies (WUE = kg [ha cm]$^{-1}$) were determined using the equations,

$$WUE_g = Dry\ grain\ mass/ET \quad [7]$$

$$WUE_b = Aboveground\ biomass\ production/ET \quad [8]$$

where dry grain mass was the weight of the dry grain per unit area (kg ha^{-1}), aboveground biomass production was the weight of the grain, stover, and cob per unit area (kg ha^{-1}), WUE_g was water use efficiency for grain (kg ha^{-1} cm^{-1}); WUE_b was water use efficiency for aboveground biomass; and ET was discussed above (Norwood, 2000; Al-Kaisi and Yin, 2003). Harvest index was calculated with the equation,

$$HI = Dry\ grain\ mass/ Aboveground\ biomass\ production \quad [9]$$

ANOVA was conducted to determine the mean differences in grain yield, stover, total biomass, harvest index (HI), and precipitation and N use efficiency. The analysis was conducted using a split-block design as described by Steel et al. (1997). Air temperatures and precipitation were measured at the site. Monthly average values are provided in Table 1. Growing degree days (GDD) (base 10°C) in 2002, 2003, and 2004 were 1390, 1392, and 1171 GDD, respectively.

RESULTS AND DISCUSSION

Grain Yields

Average grain yields ranged from 6950 to 10,340 kg ha^{-1}. Highest yields were measured in 2003 and lowest yields were measured in 2004. Grain and stover production were not influenced by an interaction between water regime and N rate (Table 2). The highest yields were observed in the 112 kg N ha^{-1} treatment and lowest yields were observed in the 0 N ha^{-1} treatments (Table 2). Applying additional N beyond the 112 kg N ha^{-1} rate did not further increase yields (Fig. 2). Several studies have shown similar results (Derby et al.,2005; Shapiro and Wortmann, 2006).

Corn grown in the high water regime had on average 13% higher yields than corn grown in the moderate yield environment. Even though yields were higher in the irrigated treatments, similar amounts of N fertilizer were required to maximize productivity in the two moisture regimes. Yield differences between moisture regimes were attributed to the supplemental irrigation water reducing yield losses due to water stress (Clay et al., 2006b).

The HI values were influenced by N rate and year. The highest HI was measured in 2003, and the lowest harvest index value was measured in the natural rainfall/0N treatment. As discussed in Clay et al. (2006b) low HI values were associated with high yields losses due to N (2870 kg grain ha^{-1}) and water stress (2180 kg grain ha^{-1}).

Corn grown in the high water regime (natural plus supplemental irrigation) had higher $\delta^{15}N$ values than corn grown in

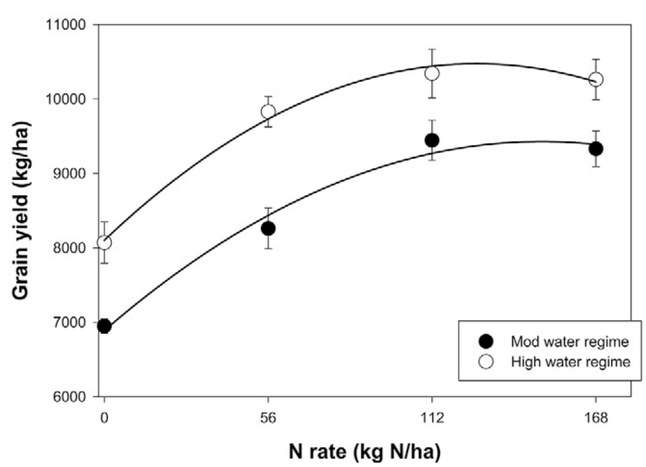

Fig. 2. The relationship between N rate and yields in the moderate (natural rainfall) and high (natural rainfall plus supplemental irrigation) water regime systems.

Table 2. The influence of water regime and N rate on grain, stover, biomass (grain + stover), harvest index (HI), and whole plant δ¹⁵N values in 2002, 2003, and 2004. In the moderate water regime plants relied on natural rainfall whereas in the high water regime plants relied on rainfall plus irrigation.

N rate	Water regime	Grain	Stover	Grain + stover	Harvest index†	Plant $\delta^{15}N$‡
kg ha^{-1}		kg ha^{-1}				‰
0	moderate	6,950	6,360	13,300	0.53	2.16
56	moderate	8,260	6,350	14,600	0.57	1.62
112	moderate	9,440	7,190	16,600	0.57	1.06
168	moderate	9,330	7,030	16,400	0.57	0.84
0	high	8,070	6,160	14,200	0.57	2.97
56	high	9,830	7,330	17,200	0.57	2.43
112	high	10,340	7,240	17,600	0.59	1.76
168	high	10,260	7,860	18,100	0.57	0.57
P value		0.297	0.110	0.114	0.151	0.27
LSD (0.05)						
	Water regime					
	moderate	8,500	6,730	15,200	0.56	1.42
	high	9,630	7,150	16,800	0.57	1.93
P value		0.004	0.190	0.028	0.064	0.058
N rate						
0		7,510	6,260	13,800	0.55	2.56
56		9,040	6,840	15,900	0.57	2.02
112		9,890	7,210	17,100	0.58	1.41
168		9,800	7,440	17,200	0.57	0.71
P value		<0.001	0.002	<0.001	0.032	<0.001
LSD (0.05)		398	563	760	0.02	0.40
Year						
2002		9,070	7,250	16,300	0.55	1.92
2003		9,660	6,180	15,900	0.61	1.88
2004		8,450	7,380	15,800	0.53	1.23
P value		<0.001	<0.001	0.149	<0.01	<0.001
LSD (0.05)		293	420		0.02	0.35

† Harvest index (HI) = grain (kg)/[grain (kg) + stover (kg)]. Biomass = grain (kg) + stover (kg).

‡ Whole plant $\delta^{15}N$ = [grain (kg) × $\delta^{15}N$ + stover (kg) × $\delta^{15}N$]/[grain (kg) + stover (kg)].

Table 3. The influence of water regime and N rate on evapotranspiration (ET), grain water use efficiency (WUE_g), and biomass (grain + stover) water use efficiency (WUE_b). In the moderate water regime plants relied on natural rainfall whereas in the high water regime plants relied on rainfall plus irrigation.

N rate	Water regime	ET	WUEg†	WUEb‡
		cm	–kg (ha cm)$^{-1}$–	
0	moderate	38.8	181	343
56	moderate	39.3	214	375
112	moderate	39.8	243	425
168	moderate	39.5	237	414
0	high	50.4	160	282
56	high	50.4	195	340
112	high	50.6	205	348
168	high	50.8	202	357
P value		0.335	0.086	0.186
LSD (0.05)			6.34	
	Water regime			
	moderate	39.4	218	389
	high	50.5	191	332
P value		<0.001	0.006	0.012
N rate				
0		44.6	170	313
56		44.9	203	358
112		45.2	223	386
168		44.9	220	385
P value		0.005	<0.001	<0.001
LSD(0.05)		0.36	9.33	19.6
Year				
2002		47	192	348
2003		42.3	234	383
2004		45.7	187	350
P value		<0.001	<0.001	<0.001
LSD (0.05)		0.42	6.6	12.5

† Grain precipitation use efficiency = WUE_g.

‡ Biomass (grain + stover) precipitation use efficiency = WUE_b.

Table 4. The influence of water regime and year on the net N balance and whole plant δ¹⁵N in the unfertilized control plots. In the moderate water regime plants relied on natural rainfall whereas in the high water regime plants relied on rainfall plus irrigation.

Year	Water regime	Plant N uptake	Grain N uptake	Net N balance	Whole plant $\delta^{15}N$
		kg N ha^{-1}			‰
	moderate	106	72	72	2.16
	high	126	85	86	2.97
	P value	0.039	0.02	0.062	0.001
2002		124	87	79	2.62
2003		96	73	76	2.41
2004		127	77	83	2.65
P value		0.039	0.089	0.844	0.326
LSD (0.05)		15	7.6		

the moderate water regime. Given that the initial soil moisture contents of the two regimes were similar, these results suggest that soil water increased soil N uptake.

Synergistic Effects of Nitrogen on Water Use Efficiency

Irrigation did not influence pre- and post-season soil water contents (data not shown). However, soil water contents following irrigation were higher in the high than the moderate water regime (Kim, 2006). Grain water use efficiency (WUE_g) increased 31% with an increase of N from 0 to 112 kg N ha^{-1} (Table 3) whereas biomass WUE_b increased 23%. The highest WUE_g and WUE_b values were observed in the 112 kg N ha^{-1} treatment. Lamm et al. (2001) found similar results with corn in Colby, KS and reported that grain WUE was increased by N additions up to 260 kg N ha^{-1}. In China, Cai et al. (2004) reported that wheat water use efficiency increased with N rate. Halvorson et al. (2004) and Al-Kaisi and Yin (2003) obtained similar results in Colorado.

Synergistic Effects of Water on Nitrogen Use Efficiency

The lack of interactions between water and N treatments on biomass or grain productivity does not imply that synergistic relationships did not occur. Synergistic relationships must occur when N fertilizer increases water use efficiency or supplemental water increases N use efficiency. Irrigation water increased the ability to use N derived from the soil from 61.6 to 67.7% of the total amount available ($P = 0.002$). Similar increases in plant $\delta^{15}N$ values (Table 4) and N fertilizer use efficiency were observed (Table 5, $P = 0.10$). The higher N use efficiencies in the high than the moderate water regime can be viewed as the result of several factors (Fig. 3). First, a large percentage of the N transported to the root is in the water transpiration stream. Second, only a portion of the inorganic

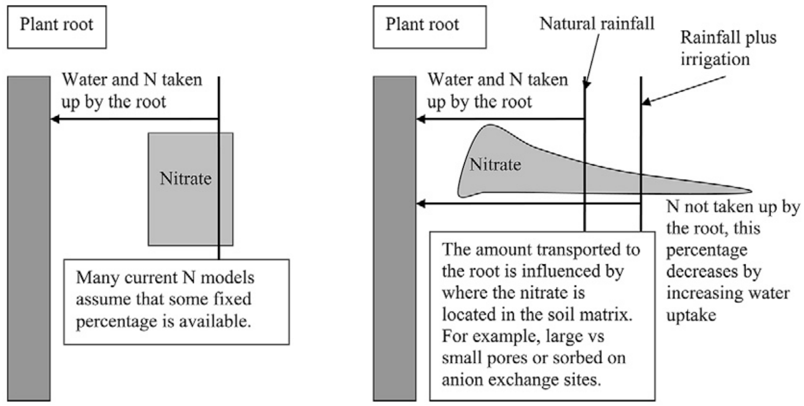

Fig. 3. A conceptual model explaining the observed synergistic relationships between N and water use efficiency. The model on the left represents the model used in many N recommendation models where a fixed amount of nitrate is assumed to be plant available, whereas the model on the right represents a system where the amount of N transported to the plant is a function of the amount of water transpired by the plant.

N is transported with the first increment of water, with additional N being transported with each additional increment of water. This transport mechanism could result from several factors. First, N in the large pores was transported to roots more rapidly than N contained in small pores. Second, sorption of nitrate to anion exchange sites slowed the transport of nitrate to the root (Clay et al., 2004). Clay et al. (2004) reported that the nitrate sorption coefficient (nitrate sorbed/nitrate in the soil solution) was 0.17 ($\pm$ 0.03 mg kg^{-1}) for a similar soil from the area. Based on these findings, a conceptual model was developed (Fig. 3). This model has fundamental differences with many current recommendation models. Nitrogen recommendation models often assume that a fixed percentage of the N contained in the soil can be used by the plant. For example, the South Dakota N recommendation model assumes that 100% of the nitrate in the surface 60 cm can be used by the plant, the western Minnesota model assumes that 60% of the nitrate can be used by the plant, and the Nebraska model assumes that approximately 50% of the nitrate contained in the surface 120 cm can be used by the plant (Shapiro et al., 2003; Gerwing and Gelderman, 2005; Rehm et al., 2006).

Results from previous studies can also be explained by the conceptual model shown in Fig. 3 (Eck, 1984; Eghball and Maranvile,1991; Al-Kaisi and Vin, 2003; Shanahan et al., 2004; Schmidt et al., 2005). For example, O'Neill et al. (2004) reported that in 13 experiments conducted in Nebraska, corn N use efficiency was higher in adequate than deficit water plots. Derby et al. (2005) reported that in North Dakota, corn yield goal-based N recommendations overestimated the N requirement in high yield environments. Bauer et al. (1965) showed that in wheat grown in North Dakota, synergistic relationship between water and N use existed. Clay et al. (2001b) reported that in Montana, wheat N use efficiency was indirectly related to the degree of water stress that the plant experienced, whereas Fusheng et al. (2003) reported that water stress reduced N use efficiency of wheat. In addition, analysis of data from Iowa (Sawyer et al., 2006) revealed that a strong relationship between the N responsiveness of a site [(Yield$_{@MRTN}$ – Yield$_{0N}$)/MRTN, where Yield$_{@MRTN}$ was the yield at the maximum return to N value, Yield$_{0N}$ was yield in the unfertilized control, and MRTN was the N rate at the published maximum return to N value] and yield potential existed (r = 0.92* for corn following corn and corn following soybean systems).

In summary these findings show that synergistic relationships exist between water and N, with N additions increasing water use efficiency and water additions increasing N use efficiency. Based on these findings a conceptual model relating water and N uptake was developed. These findings have implications for precision farming because if yields across landscapes are limited by water stress, then the responsiveness of corn to N fertilizer will be impacted by landscape position. The conceptual model (Fig. 3) could be implemented by converting the k constant in the yield goal equation to a variable. For example, in areas where water has a small impact on yield, the constant could be reduced from 21.4 to 19.6 kg N (Mg grain)$^{-1}$. It is important to point out that to account for differential mineralization across the landscape, the constant may

Table 5. The influence of water regime and N rate on the concentration of N in the biomass, total biomass N, inorganic N at the of a growing season, grain nitrogen use efficiency (NUE), and the amount of N contained in the grain. In the moderate water regime plants relied on natural rainfall, whereas in the high water regime plants relied on rainfall plus irrigation.

N rate	Water regime	Biomass N concentration	Biomass N	Inorganic N final	Grain NUE	Grain N uptake
kg N ha^{-1}		g kg^{-1}	– kg N ha^{-1}–		%	kg N ha^{-1}
0	moderate	7.9	106	55		72
56	moderate	10.4	154	76	54	103
112	moderate	11.3	188	87	45	123
168	moderate	11.5	191	130	33	127
0	high	9.0	126	51		87
56	high	10.4	180	72	68	124
112	high	11.7	205	86	45	136
168	high	11.5	212	88	30	135
P value		0.01	0.825	0.095	0.053	0.149
LSD(0.05)		0.06		10.9	4.86	
	Water regime					
	moderate	10.3	160	87	44	106
	high	10.6	181	74	48	120
P value		0.082	0.008	0.13	0.1	0.007
N rate						
0		8.4	116	53		80
56		10.4	167	74	61	113
112		11.4	196	86	45	129
168		11.5	201	109	31	131
P value		<0.001	<0.001	<0.001	<0.001	<0.001
LSD(0.05)		0.03	9.9	16.8	7	5
Year						
2002		9.9	163	85	33	111
2003		10.2	167	68	59	118
2004		11.3	180	88	46	111
P value		<0.001	<0.008	<0.001	<0.001	0.02
LSD(0.05)		0.05	11	16.8	7	6

require further modification (Rashid and Voroney, 2005; Soon and Malhi, 2005; Clay et al., 2006a; Dharmakeerthi et al., 2006).

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